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Ultrasonic sensing of properties of eco-friendly cement mortar

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Abstract: Cement is one of the essential construction materials required to develop concrete and mortar; therefore, it is vital in developing cities' infrastructure and maintaining human civilisation. However, cement production is recognised as a major source of many environmental problems, including air and water pollution. This paper, therefore, focused on the partial replacement (from 0 to 40%) of cement in the mortars with industrial by-products and on the application of ultrasonic waves as a sensing approach to evaluate the mechanical properties of the new cement mortar. The compressive strength of the eco-friendly mortar was measured at ages of 7, 14, and 28 days, and the results showed the best compressive strength of the eco-friendly mortar was 19.8 MPa at 28 days compared to 23.9 MPa of the reference mix. Additionally, a good agreement was noticed between the ultrasonic pulse velocity (UPV) and the compressive strength confirming the applicability of the UPV for compressive strength sensing.

Keywords: Eco-friendly; concrete; compressive; ultrasonic.

1. Introduction

The role of cement in developing efficient infrastructure is undeniable; cement is the main component of concrete that is widely used in the construction of the main parts of all infrastructure components. For example, it is used in bridges, tunnels, houses, pavements, sewers, etc. [1]. With the increase in population and the need for urbanisation to accommodate this increase, cement production has witnessed significant growth in the last few decades. However, besides the importance of cement in maintaining civilisation, the cement industry is responsible for severe pollution of the environment [2]. Thus, the cement industry's consequences became clearer; for example, the gaseous emissions have reached a severe level in the last few years, such as the increase in carbon monoxide and dioxide that reached elevated levels in the atmosphere [3]. The accumulation of harmful gases in the atmosphere triggered global warming and climate change in general. In addition, the effluents of the cement mixes are usually contaminated with particulates, turbidity and high alkalinity [4].

Furthermore, the solid wastes produced from concrete demolition represent a problem for the local authorities due to the difficult and expensive handling of such wastes [5]. To avoid these

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negative impacts, many researchers used alternatives to cement in concrete and cement. These alternatives generate fewer emissions and save natural resources.

In this context, this paper investigates the use of industrial by-products, namely ground granulated blast furnace slag (GGBS) and Pulverised Fuel Ash (PFA), to produce eco-friendly concrete. Additionally, assessing the mechanical properties of the eco-friendly mortar using ultrasonic sensors and conventional compressive strength.

2. Materials and Methods

Cement mortar samples were prepared in two groups; the first group was the reference samples RS (4 samples) which were prepared using Ordinary Portland Cement (OPC), while the second group was the eco-friendly samples (ES) (36 samples), which were prepared by adding different ratios of PFA and GGBS as partial replacement of the OPC, as shown in Table 1.

The prepared samples were developed in 10×10×10 cm moulds and left in the laboratory for 24 hrs before demoulding them and soaking them in a water tank (curing process). The compressive strength of these samples was measured at the age of 7, 14 and 28 days. Three samples of the ES were tested at each age, along with an RS sample.

Table 1. Mixing ratios for RS and ES samples.

Sample	OPC	PFA	GGBS
RS	100 %	0 %	0 %
ES1	70 %	15 %	15 %
ES2	50 %	25 %	25 %
ES3	30 %	35 %	35%

3. Results

The prepared samples were taken from the curing tank, and the extra moisture was removed before testing the compressive and ultrasonic pulse velocity (UPS). The tests usually started by the UPS then the compressive strength was measured. Then, the results were compared and correlated. The obtained results for the compressive strength at the age of 7, 14 and 28 days are shown in Tables 2, 3 and 4, respectively.

Table 2. Compressive strength at the age of 7 days.

Sample	OPC	PFA	GGBS	Compressive strength (MPa)
RS	100 %	0 %	0 %	10.6
ES1	70 %	15 %	15 %	9.1
ES2	50 %	25 %	25 %	5.5
ES3	30 %	35 %	35%	5.1

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Table 3. Compressive strength at the age of 14 days.

Sample	OPC	PFA	GGBS	Compressive strength (MPa)
RS	100 %	0 %	0 %	11.8
ES1	70 %	15 %	15 %	10.7
ES2	50 %	25 %	25 %	7.6
ES3	30 %	35 %	35%	6.9

Table 4. Compressive strength at the age of 28 days.

Sample	OPC	PFA	GGBS	Compressive strength (MPa)
RS	100 %	0 %	0 %	13.2
ES1	70 %	15 %	15 %	12.4
ES2	50 %	25 %	25 %	9.8
ES3	30 %	35 %	35%	8.8

The results listed in the Tables above show:

It could be noticed the application of the PFA and GGBS as partial replacements of the OPC in cement mortar did not provide benefits in terms of compressive strength. Mix ES1 showed less reduction in the compressive strength in comparison with ES2 and ES3. For example, after 7 days of curing, the decrease in the compressive strength of the ES1, 2 and 3 was 14.2%, 48.1%, and 51.9% compared to RS, respectively. However, this decrease was improved at the age of 14 and 28 days. For example, after 28 days of curing, the decrease in the compressive strength of the ES1, 2 and 3 was 6.1%, 25.8%, and 33.33% compared to RS, respectively. This indicates that the PFA and GGBS are inactive materials at early ages and require enough time to interact with the cement. The main conclusion of these experiments is that the use of 30% PFA and GGBS as a partial replacement for OPC is convenient for strength and the environment.

The results of the effects of the PFA and GGBS on the performance of the cement mortar are agreed with the results in the literature [6, 7].

The results of the UPV are shown in Figure 1, which shows similar behaviour to that noticed in the compressive strength, where the UPV values increased with age. This indicates the progress of the reaction between the PFA and GGBS (the mortar gets harder over time). Thus, the UPV method is suitable for assessing the compressive strength of the cement mortar. It must be mentioned that the nondestructive tests for cement mortar and concrete properties have developed in the last few years, such as using electromagnetic waves. Therefore, for future studies, use other nondestructive test methods to assess the strength of the cement mortar.

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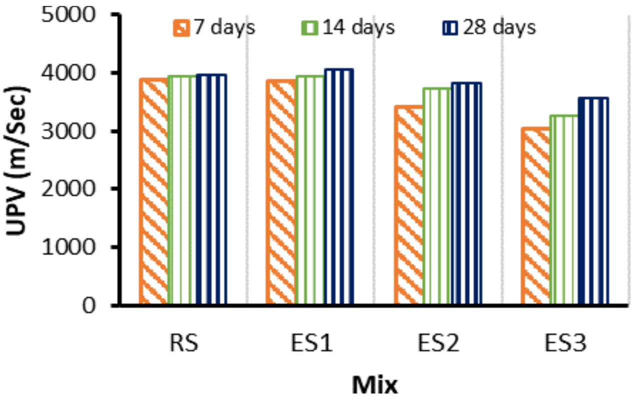

Figure 1. UPV values for the studied samples.

2. Conclusions

This paper investigated the applicability of industrial by-products as a partial replacement (from 0 to 40%) of cement in the mortars, and it applies the ultrasonic waves as a sensing approach to evaluate the mechanical properties of the new cement mortar.

Based on the findings of the experiments in this study, some critical points could be drawn as follows:

1. Replacing OPC with PFA and GGBS in cement mortars negatively affects compressive strength.

2. Increasing the curing time helps to limit the decrease in the compressive strength of the cement mortar.

3. The best percentage of PFA and GGBS in cement mortar is 30% (of cement).

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